Integrated RF Antenna and Solar Array for Spacecraft Application

Mark Zawadzki
John Huang

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA 91109

Introduction

There is a critical need for enabling technologies that will reduce the mass, physical size and cost of major spacecraft components. Virtually all spacecraft include at least one large-aperture telecommunications antenna and a large-aperture solar array. Combining these large apertures will achieve critical goal of reducing spacecraft mass, stowage volume, cost, and deployed surface area, without significantly affecting the performance of either the antenna or solar array [1]. This will also facilitate spacecraft maneuvers and attitude control, and increase the field of view of scientific instruments. The performance of the RF antenna and solar array both vary with the cosine of the angle from their broadside directions. This would allow significant mission flexibility and the potential to optimize the integrated array pointing-angle between the Sun and the Earth to obtain the proper combination of electrical power and RF gain. Most deep space missions have Sun/Earth subtended angles of less than 40°. If an integrated array were pointed half-way between the Sun and the Earth with a 40° subtended angle, then this would represent only a 0.5 dB loss for the antenna and only a 6% reduction in solar array output.

The objective of this research effort was to develop and demonstrate an integrated high-gain RF antenna and solar array technology for spacecraft application. The RF antenna technology selected was a printed microstrip reflectarray, which uses a large number of thin crossed-dipoles as the radiating elements. A microstrip reflectarray has the capability of integration with a solar array for the following reasons:

1) the reflectarray consists of many array elements printed on a flat panel, which is illuminated by a feed horn and does not require a power division network
2) the electrical characteristics of a reflectarray are similar to those of a conventional curved parabolic reflector, but since its aperture is physically flat and its elements function without power division network, it is amenable to integration with a flat solar panel; and,
3) the microstrip dipoles that are used as array elements are physically very thin, and will not significantly reduce blockage of sunlight to the solar cells situated below the RF elements.

Although both the microstrip reflectarray and the solar array are very thin in profile and low in mass, they separately require massive and large support panels to maintain their required aperture flatness. By combining the antenna and solar panels, thus eliminating one support structure, significant mass and launch vehicle stowage volume savings can be achieved. The goal of this research effort was to breadboard and test a half-meter-diameter aperture that was populated by both X-band reflectarray crossed-dipole elements and silicon solar cells.

Antenna Description

The reflectarray in this design consists of 408 X-band crossed-dipole elements that are etched onto a Kapton substrate, which is then laid on top of a standard solar array. The element spacing on the reflectarray was chosen to fit the solar cell size. The integrated solar/RF array consists of four basic components: 1) a mechanical support structure; 2) an X-band feed horn; 3) a solar array with 198 silicon solar cells; and, 4) a thin-film polyimide material (Kapton) with 408 printed reflectarray crossed dipoles. Fig. 1 shows a photograph of the final antenna, and Fig. 2 shows a sketch of the antenna cross-section with a top view of a single solar cell. Support for both the reflectarray and the solar cells is provided by a circular anodized aluminum plate, which is 0.5m in diameter and 6.4mm thick. A tripod strut assembly is used to hold a circularly-polarized, conical feed-horn with a 3dB-beamwidth of 39° and a -9dB edge taper to the aperture. The f/D ratio of the structure is 0.75. The solar cells are secured directly onto of the anodized aluminum plate with a silicon-based adhesive. A 1.52mm-thick (60mil) coverglass, which serves to protect the solar cell in space, is bonded to the top of each cell. This coverglass also provides the necessary vertical separation between the solar cells and the dipoles. The printed crossed-dipoles are etched onto a sheet of 0.051mm-thick (2mil) Kapton membrane, and secured to the top of the coverglasses with a silicon-based adhesive. Even though Kapton absorbs a significant amount of light energy in the same spectral region as the solar cells, which reduces the amount of light that reaches the solar cells, it was chosen because it is readily available in large pieces with a thin copper coating that is easily etched. This was a carefully considered trade. Polymers with higher optical transparency would be favored for future versions of the integrated array.

The reflectarray was designed using software developed by The University of Massachusetts [2], and used the Moment Method technique. Since the effect of the inhomogeneous nature of the cross-section, particularly the irregular ground plane (see Fig. 2), on the performance of the reflectarray was unclear, the strategy adopted was to etch three separate reflectarrays - one designed at the desired center frequency of 8.4GHz, and the other two ±3% away.

Results and Discussion

The solar array results were very good. While the Kapton membrane alone (no dipoles) reduced the power output of the cells by 40.5% (from the reference of using just coverglasses), the addition of the dipoles only reduced the output by about 10%, which would then be the expected overall loss if an optically clear membrane were used. This loss in power could be easily regained by increasing the area of the solar array by 10%, or by increasing the sides of a square array by only 5%. This is a very small amount considering the overall reductions of mass and volume realized by combining the RF and solar arrays.

The news for the RF portion, while encouraging, was not as good. As can be seen from the radiation patterns in Fig. 3, the reflectarray did form a coherent beam in the far field; however, the measured aperture efficiency was only about 10% - far from the expected value of 40%. This relatively low efficiency is likely the result of ~~the~~ two main factors. First, the electrical characteristics of the overall reflectarray substrate, especially the inhomogeneous ground plane, were not well-understood or well-considered in the design, mainly because the fine, inhomogeneous silver grid on the top surface of the solar cells is difficult to characterize. The second factor has to do with the reflectarray element itself. It was felt that elements other than crossed-dipoles should be examined in an attempt to find an optimal element. Future work to improve the RF performance would focus on these two areas. Nevertheless, the result of this development indicates that the integration of large antenna and solar array apertures is highly feasible.

Acknowledgements

The work of Carol Lewis and Bob Mueller from JPL on the solar array portion of the antenna is acknowledged here. The research in this paper was carried out by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

References

1. J. Huang, "Capabilities of Printed Reflectarray Antennas", IEEE Phased Array Systems and Technology Symposium, Boston, Massachusetts, October 1996, pp. 131-134.

2. D. M. Pozar, "Reflectarray Antenna and Solar Array Integration for Spacecraft Applications", University of Massachusetts at Amherst, Final report prepared for JPL under Contract No. 960740, March 1997.

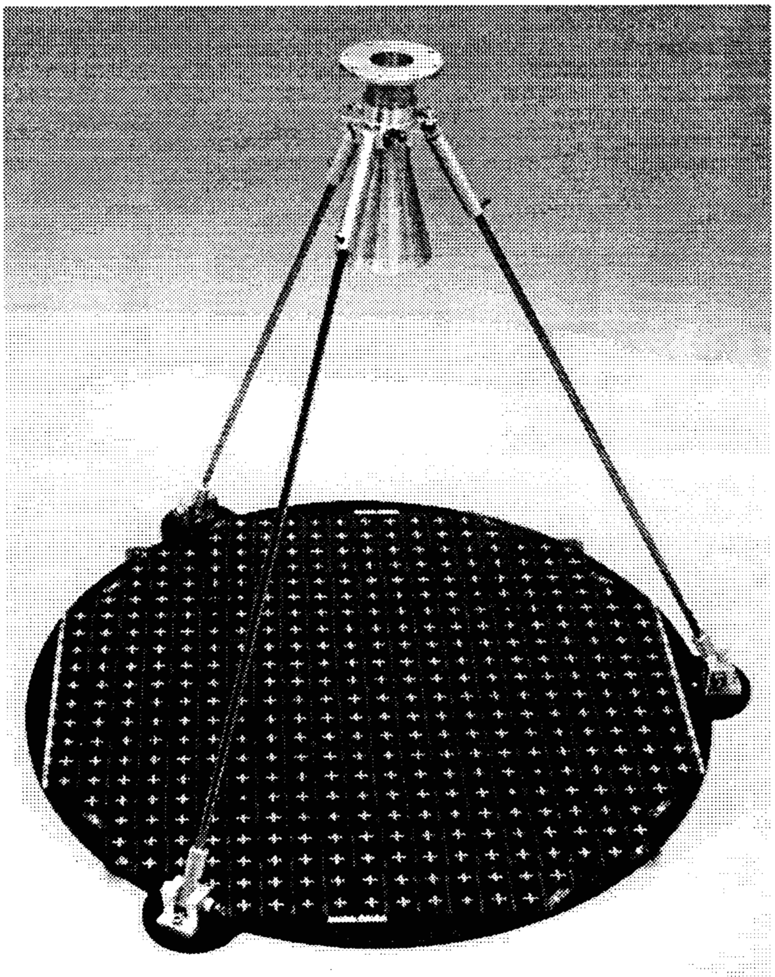

Figure 1. Photograph of integrated solar array with reflectarray crossed-dipole elements.

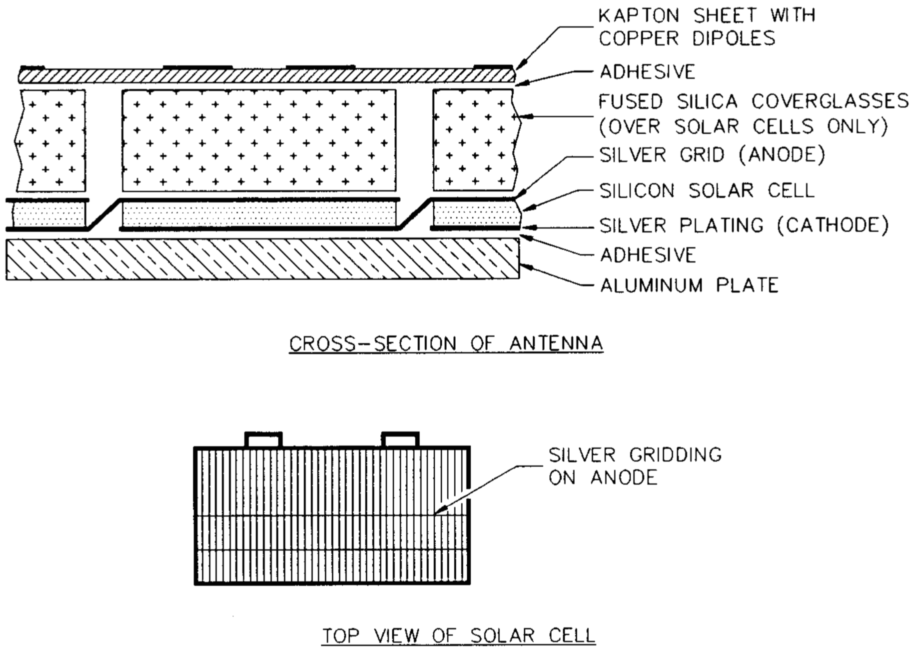

Figure 2. Cross-section of antenna and top view of solar cell.

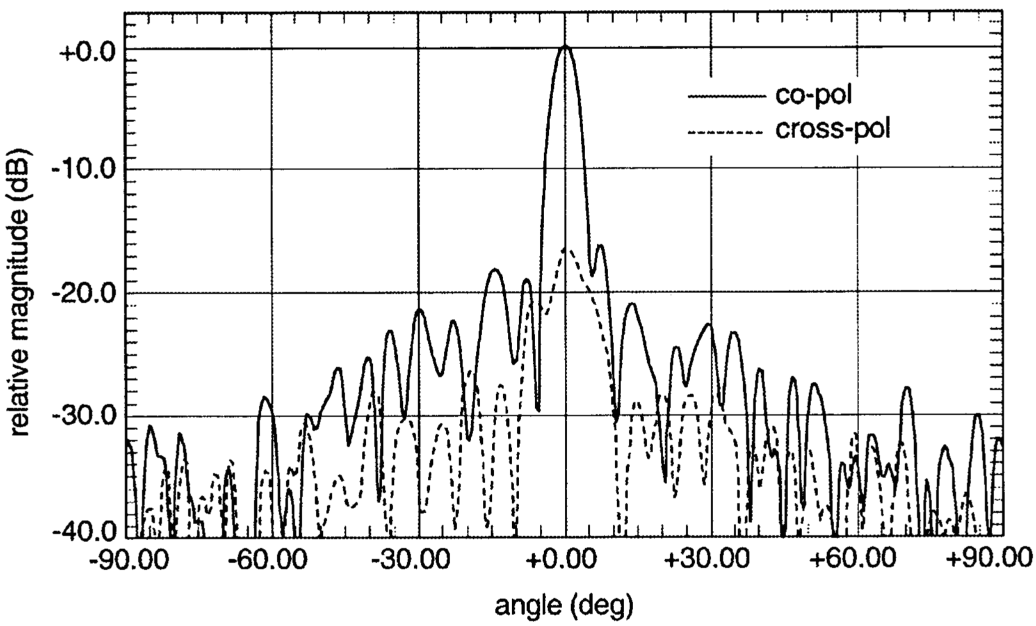

Figure 3. Measured radiation pattern of the integrated antenna at 8.5GHz